

Final Status Report for NAG5-1007

Development of High Efficiency Opaque Photocathodes for the Region 900Å to 1200Å

Contract #NAG5-1007, Dr M. Lampton and Dr O. Siegmund

Status Report.

During this program we have made progress in three main areas: Investigation of the basic properties of candidate photocathode materials, measurement of the quantum detection efficiency (QDE) of KCl, RbBr and CsBr as a function of wavelength and incident angle, and assessment of the stability of these photocathodes.

Photocathode Materials Study

The objective of this program is to develop high efficiency photocathodes, deposited on microchannel plates (MCP's), for $\lambda = 900\text{\AA}$ to 1200\AA . We initially proposed to investigate the materials, CsBr, CsCl, KI and RbBr. Examining the available data on these materials, and comparing to results obtained with CsI and KBr, we have decided to change the materials list to CsBr, KCl and RbBr. This decision was based on the water solubility data, which shows that CsCl and KI have high solubility which is likely to result in rapid photocathode deterioration.

We have found existing data on the reflectivity and the absorption coefficient for all of the materials. This indicates that there are no problems with high reflectivity, and the expected QDE peaks are within the required range. For KCl the band gap + affinity is 8.9 eV which would result in a photoelectric threshold at $\sim 1400\text{\AA}$, with a 2x bandgap QDE minimum at $\sim 700\text{\AA}$. We therefore expect a QDE peak in the 900Å to 1000Å range. For RbBr the bandgap + affinity is 8.1 eV, giving a threshold of 1550Å, a QDE minimum at 775Å, and a peak at about 1100Å. CsBr has a bandgap + affinity of 8.2 eV also so should look similar to RbBr. RbBr and CsBr have solubility that is slightly greater than CsI, but KCl has smaller solubility than CsI. From photoyield data we estimate that all these materials should have QDE which is close to that of KBr, and therefore worth investigation. NaCl was also considered initially, but since its QDE would be similar to KCl, and therefore inferior to KBr, we did not pursue measurement of NaCl.

QDE Measurements

We have measured the QDE of KCl, RbBr and CsBr during this project. To obtain a complete picture of the operation and characteristics of the photocathode layer, the QDE was measured as a function of the wavelength and of the angle of incidence, with, and without a retarding field. To obtain representative results for the QDE we initially determined some of the cathode fabrication requirements likely to optimize the cathode QDE. The MCP substrates for the cathode layers were cleaned, and then baked just before the cathode deposition to eliminate contamination problems. Since we wished the QDE to be maximized for all wavelengths, and incident angles, we also determined that a thick layer which penetrates deeply into the MCP pores should be best. Thus we arrived at a deposition angle of 10° with a front surface thickness of $15,000\text{\AA}$, giving about 1000\AA thickness in the MCP pores. We also established

that evaporation rates of 50Å/sec produced the best QDE results. Following the depositions the cathode layers were always transported in argon to minimize exposure to humidity.

KCl

KCl has not been used extensively as a photocathode material, but there have been several measurements of yield. Our measurements of the QDE of KCl are presented in Fig. 1. The valence band - conduction band gap for KCl is 8.4eV, with an electron affinity of 0.4eV. The onset of photoemission is observed at ~1400Å, which is that expected from the 8.8eV photoelectric threshold. The QDE increases to a peak >30% at ~900Å before falling to a minimum of ~16% at 670Å. The same features are evident in the yield data at the same wavelengths. Examination of photoelectron energy distributions from 720Å to 660Å shows clearly the reduction in emission of primaries with energies of 7eV - 9eV, along with the increase in emission of secondaries with energies of ~1eV. This directly demonstrates the change from single to multiple electron emission by 660Å (18.8eV). The QDE minimum at 660Å is at slightly shorter wavelength than expected (17.6eV, 700Å). Below 650Å the QDE rapidly increases to a peak value of ~40% at 450Å as the secondaries increase in energy. There seems to be some sub-peak structure that may be due to multiple electron emission as seen in CsI and KBr. The decrease in the QDE below 450Å follows the decrease in absorption coefficient.

The angular dependence of the KCl QDE shows the characteristic drop off in QDE at small graze angles due to high reflectivity (Fig. 2). The drop off in QDE at large graze angles is quite slow, being characteristic of the situation where the escape length for photoelectrons is larger than the absorption depth for the radiation. Also the contribution of the interchannel web to the QDE is quite significant, particularly at the QDE peaks.

We have written a paper on these results which is due to appear in Applied Optics this month.

RbBr

RbBr is also a material that has not been previously used as a cathode material, although some photoyield measurements have been made. Our measurements of the QDE of RbBr are presented in Figure 3. The valence band - conduction band gap of RbBr is 7.7eV, with an electron affinity of 0.4eV. We observe the onset of photoemission at ~1600Å, which is close to that expected. The QDE increases to a broad, flat, peak extending from 1150Å to 900Å with a value of >40%. The small dip at ~1120Å is due to a reflectivity feature in the RbBr spectrum analogous to the similar feature found for KBr. However, for RbBr the dip is much smaller than KBr, and seems in keeping with the 10% reflectivity found for RbBr compared to 30% reflectivity for KBr. Centered at ~775Å there is a broad QDE minimum where the QDE drops below 25%. This correlates very closely with 2X the band gap + affinity, and is corroborated by the appearance of a large low energy peak in the photoelectron energy spectra for wavelengths below 760Å. Thus the transition to two low energy photoelectrons is responsible for the 775Å minimum. Below 700Å the QDE rapidly rises to a peak of 50% at 600Å, but then falls to a minimum of ~25% at 475Å before rising again to a peak of ~40% at 400Å. These structures may be interpreted in terms of multiple

photoelectron emission, with the dip at 475\AA being coincident with $3\times$ the band gap + affinity ($\sim 500\text{\AA}$). Below 400\AA the QDE drops gradually to a minimum (QDE 20%) at 170\AA , then a sharp QDE peak occurs at $\sim 70\text{\AA}$. This behavior closely matches the trend in absorption coefficient which displays a minimum at $\sim 170\text{\AA}$ and has a sharp resonant feature (d-f) at $\sim 83\text{\AA}$. In general the short wavelength behavior of RbBr closely resembles KBr.

The angular dependence of the RbBr QDE also shows the characteristic drop off in QDE at small graze angles due to high reflectivity. The drop off in QDE at large graze angles is slow, characteristic where the escape length for photoelectrons is larger than the absorption depth for the radiation. The contribution of the interchannel web to the QDE is very large, particularly at the QDE peaks. All these factors suggest that the escape probability for photoelectrons in RbBr is very high.

CsBr

CsBr has been used as a photocathode material, but only at the shorter wavelengths ($<68\text{\AA}$), and there are some measurements of the photoyield. We have measured the QDE of CsBr as a function of wavelength from 44\AA to 1200\AA . The results show a large QDE peak ($> 60\%$ QDE) centered at $\sim 110\text{\AA}$, which coincides with a strong resonant absorption peak (d-f transitions). There is a weak QDE minimum at $\sim 170\text{\AA}$ to 200\AA that corresponds with a minimum in the absorption coefficient. Above 300\AA CsBr shows only small QDE features compared with RbBr and KCl, the QDE varying between 25% and 40%. There is a QDE peak (40%) at $\sim 600\text{\AA}$ and a small minimum (27% QDE) at $\sim 500\text{\AA}$. These appear in roughly the same position as the equivalent features in RbBr. The QDE minimum at $\sim 800\text{\AA}$ drops only to 25% and is not as strong as the same feature in RbBr. Between 900\AA and 1200\AA the QDE reaches $\sim 35\%$, but has a minimum centered at 1020\AA ($\sim 25\%$). In terms of QDE and the wavelength dependence CsBr seems closer to CsI than RbBr.

Photocathode Stability

KCl

Four months after the initial QDE measurements the cathode QDE was measured at several wavelengths to examine the stability of KCl. During the four month period the detector was stored in a dry nitrogen box but we estimate that, in the course of measurements and handling, the cathode was exposed to air at 25% to 50% relative humidity for ~ 8 hours. The QDE results obtained after this interval are compared with the initial results in Fig 4. The QDE values after the storage period are generally within measurement errors of the initial results for wavelengths below 1066\AA . However, the later measurements show a statistically meaningful drop (30% to 40%) in QDE for $\lambda = 1216\text{\AA}$ and longer wavelengths. The drop in QDE may be due to two processes. Hydration of the surface layers of the photocathode material may result in energy levels within the band gap. These will cause higher photoelectron energy losses and therefore reduce the QDE. Another process is the resolution of the cathode material into large globules, as has been seen for CsI. This exposes some of the channel wall area which has a lower QDE than the cathode material.

RbBr

The stability of RbBr was evaluated immediately after the initial QDE measurements. A subset of six wavelengths were chosen and the QDE re-evaluated after controlled exposure to atmosphere at 45% to 50% relative humidity (Fig 5). Over 7 hours the QDE drops by about 25% at short wavelength, and by ~60% at long wavelength, but the QDE drop off rate decreases with time. The drop off after only 1 hour is ~15% at 256Å, and ~45% at 1216Å. The degradation mechanisms described above are also applicable in this case. Nevertheless, for limited exposure times RbBr retains very high QDE values that are applicable to instrumentation in the 900Å to 1200Å range.

CsBr

The stability of CsBr is currently being evaluated, but initial indicators suggest that CsBr stability falls somewhere between CsI and KBr.

Publications

Soft X-Ray and Extreme Ultraviolet Quantum Detection Efficiency of Potassium Chloride Photocathode Layers on Microchannel Plates, O.H.W. Siegmund, E. Everman, J. Hull, J. Vallerger, and M. Lampton, to appear in, *Applied Optics*, Oct, 1988

Figure 1.

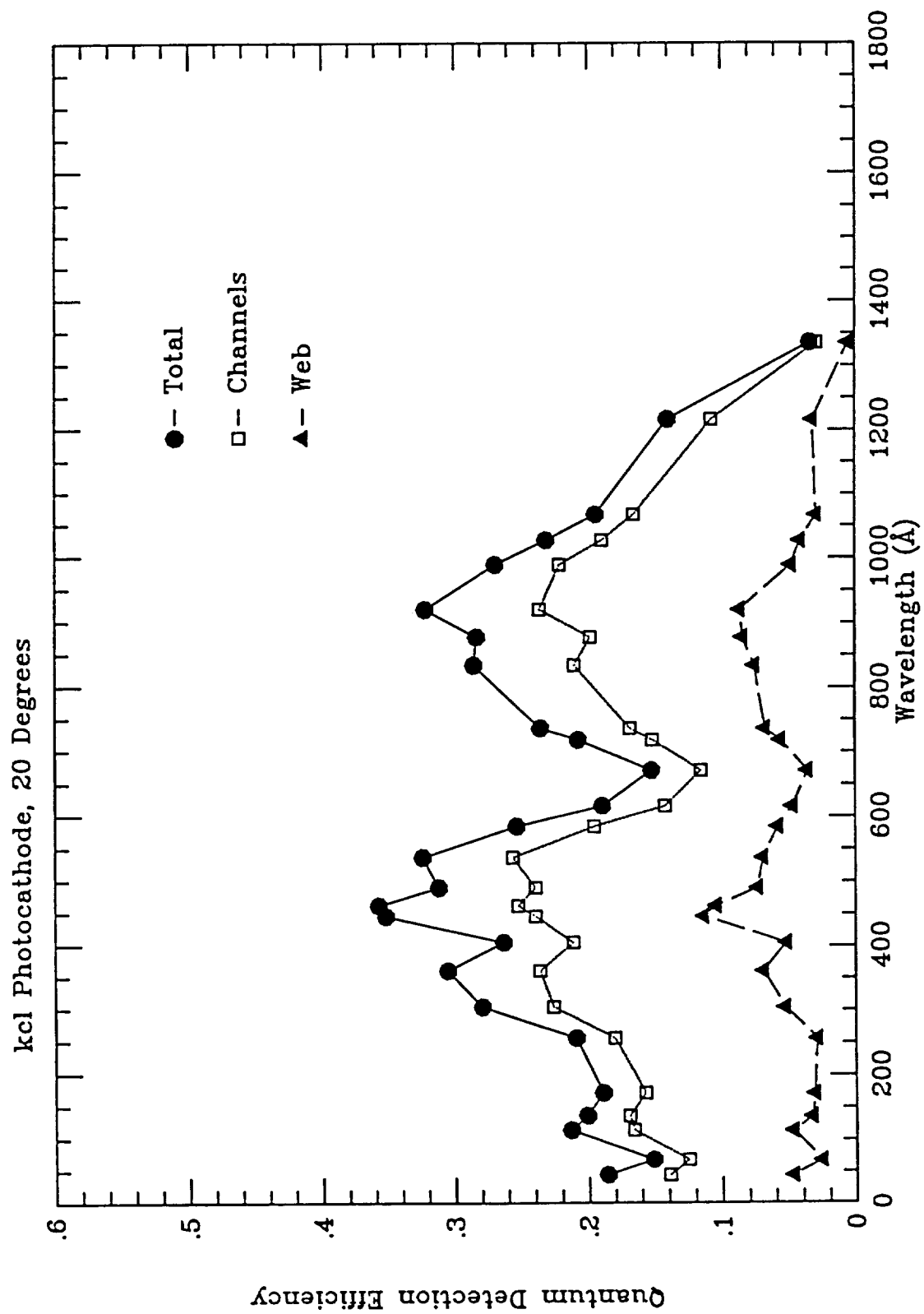


Fig. 2 : Quantum detection efficiency vs. graze angle to the channel axis for a 15,000Å thick opaque KCl photocathode using 920Å radiation with a 145 V mm⁻¹ repelling field. Errors are as described in the text.

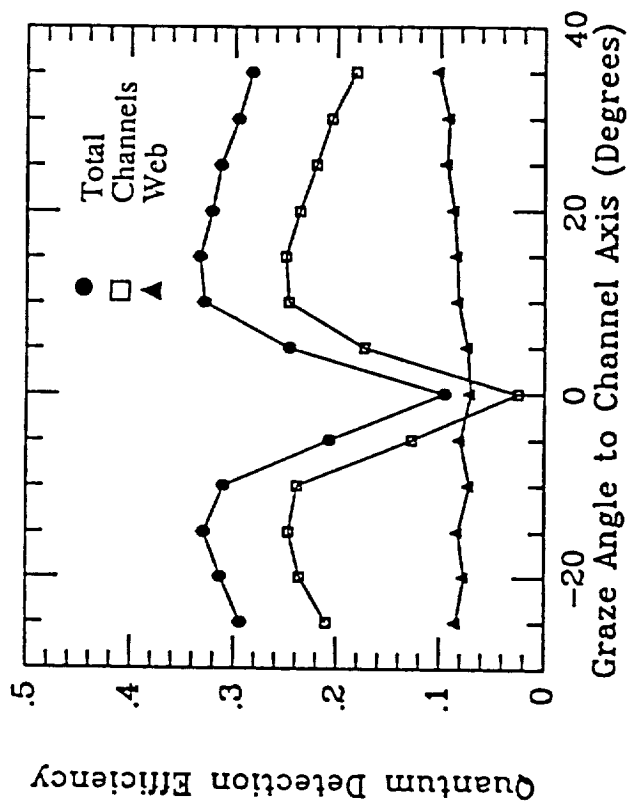


Figure 3.

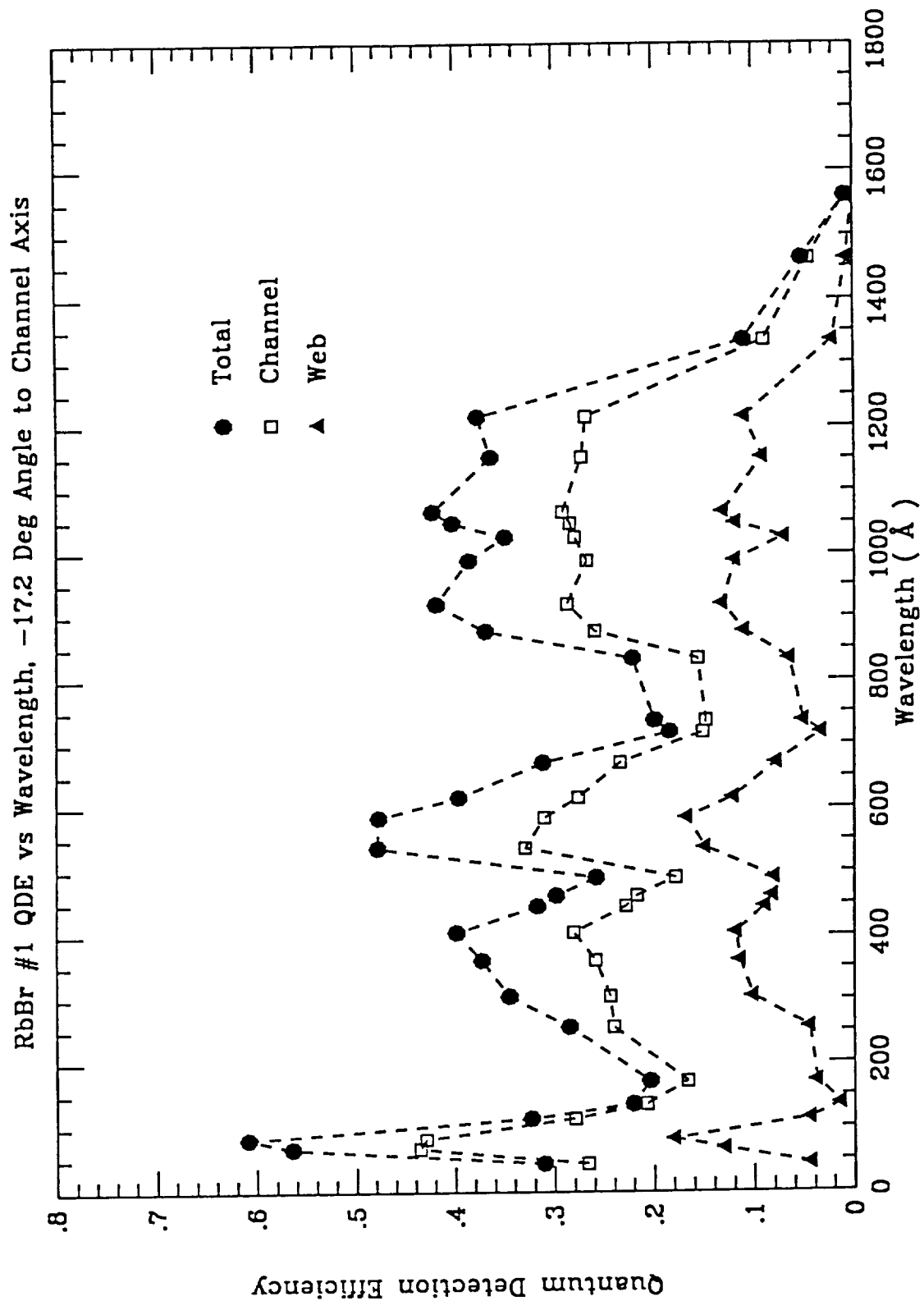


Fig. 4 : Quantum detection efficiency vs. wavelength for a 15,000Å thick KCl opaque photocathode at a 15° graze angle to the channel axis before, and after, exposure to atmosphere and storage, (145 V mm⁻¹ repelling field). Errors are as described in the text. ● Initial measurements, □ Measurements after storage period.

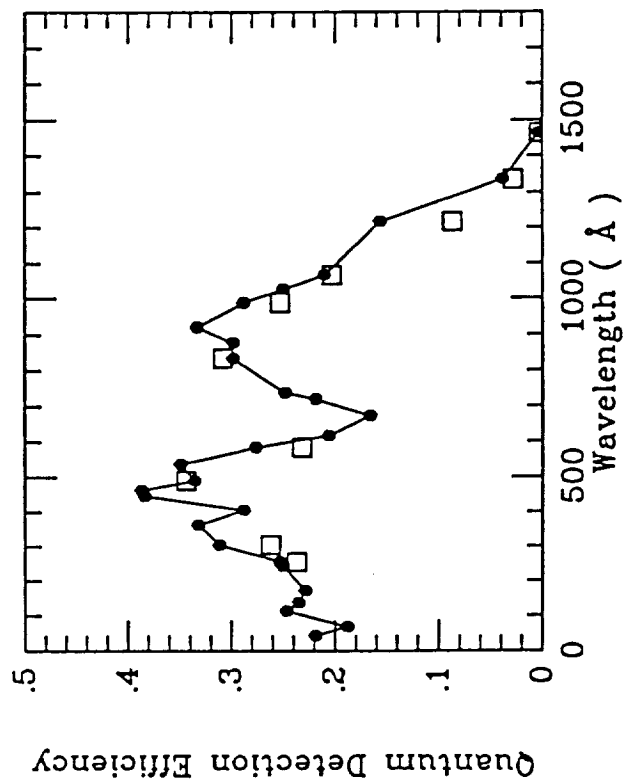


Figure 5. RbBr Lifetest

